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	Subsystem/Office Anticoincidence Detector Subsystem	
Document Title <b>LAT ACD Phototube Helium Sensitivity</b>		

**Gamma-ray Large Area Space Telescope (GLAST)**

**Large Area Telescope (LAT)**

**ACD Phototube Helium Sensitivity**

## Gas Diffusion into GLAST ACD Photomultipliers

Rogers et al. (1954, J. Applied Physics 25, #7, 868) give the partial pressure  $p_i$  of component  $i$  in a vessel (initially evacuated) of volume  $V$ , surface area  $A$ , and wall thickness  $d$  as a function of time, for a partial pressure differential of  $\Delta p_i$  :

$$p_i = \frac{AD_i S_i}{Vd} \Delta p_i \left\{ t - \frac{d^2}{6D_i} - \frac{2d^2}{\pi^2 D_i} \sum_{m=1}^{\infty} (-1)^m \frac{e^{(-m^2 \pi^2 D_i t / d^2)}}{m^2} \right\}.$$

In the above equation,  $D_i$  and  $S_i$  are the diffusion coefficient ( $\text{cm}^2/\text{s}$ ) and solubility (pure number), respectively, for component  $i$ . The product  $D_i S_i$  is the corresponding permeability  $k_i$ . The permeability  $k$  has the same dimensions as does the diffusion coefficient  $D$  ( $\text{cm}^2/\text{s}$ ), but much of the literature gives  $k$  in  $(\text{cm}^3 \text{ atm mm})/(\text{s cm}^2 \text{ cmHg})$ . Those numbers must be multiplied by the conversion factor  $(76 \text{ cmHg/atm})/(10 \text{ mm/cm}) = 7.6$ , to convert to  $\text{cm}^2/\text{s}$ .

We obtain values of the permeability  $k$  from Altemose (1962, Proc. 7th Symposium on the Art of Glassblowing):

$k_i(\text{cm}^2/\text{s}, 25^\circ\text{C})$	Pyrex (Corning 7740)	Borosilicate glasses (Corning 7052 or 7056)	Soft glasses (Corning 0080 or 0120)
Helium	$7.6 \times 10^{-11}$	$5.0 \times 10^{-12}$	$1.7 \times 10^{-14}$
Neon	$7.6 \times 10^{-15}$	$1.2 \times 10^{-15}$	$7.6 \times 10^{-25}$

(Note: Values less than about  $10^{-11}$  have been obtained by temperature extrapolation, since at room temperature they are too small to be measured. However, this seems to be a reliable extrapolation, at least for rough estimates.)

The time constants for establishing steady flow require the diffusion coefficient  $D_i$ , which is seldom found in the literature;  $D_i$  must therefore be found from  $D_i = k_i/S_i$ . Solubilities  $S_i$  are given by Altemose (1961, J. Applied Physics 32, #7, 1309; Table III) for helium in a variety of glasses

at temperatures in the range 100°C-500°C. Altomose states that there is no evidence for variation of  $S_i$  with temperature or pressure, so we use those values also at room temperature.

There is additional information on solubilities in a recent book by J.E. Shelby, *Handbook of Gas Diffusion in Solids and Melts* (ASM). However, the solubilities  $S_i$  are still rather poorly determined. For helium in fused silica, the measurements range over 0.0042-0.0075; we will use 0.006. For neon in fused silica, the measurements range over 0.0008-0.0054; we will assume 0.003. Thus the neon solubility seems to be roughly half that of helium, at least in fused silica; we will use that ratio for other glasses also. For helium, Altomose gives solubilities of  $\sim 5 \times 10^{-3}$  in Pyrex and borosilicate glasses, and  $1.2 \times 10^{-3}$  in soft glasses. We will use half those values for neon. We then obtain the following diffusion coefficients:

$D_i(\text{cm}^2/\text{s}, 25^\circ\text{C})$	Pyrex	Borosilicates	Soft Glasses
Helium	$1.5 \times 10^{-8}$	$1.0 \times 10^{-9}$	$1.4 \times 10^{-11}$
Neon	$3.0 \times 10^{-12}$	$4.8 \times 10^{-13}$	$1.3 \times 10^{-21}$

The time constants are of order  $\tau_i = d^2/(\pi^2 D_i)$ , from which we obtain the following values:

$\tau_i(\text{s}, 25^\circ\text{C})$	Pyrex	Borosilicates	Soft Glass
Helium	$6.7 \times 10^4$	$1.0 \times 10^6$	$7.1 \times 10^7$
Neon	$3.3 \times 10^8$	$2.1 \times 10^9$	$7.7 \times 10^{17}$

Thus for helium the diffusion approaches steady-state in a few days through Pyrex, a few weeks through borosilicate glasses, and in a few years through soft glasses. For neon, steady-state is approached in a few dozen years through Pyrex, a few hundred years through borosilicates, and through soft glass, about the time the Universe is 3 times its present age.

Ignoring the time constants, we now examine the steady-state flow, given by

$p_i = (A k_l \Delta p_l t)/(Vd)$ . The worst case (surface to volume ratio) PMT under consideration (Hamamatsu R1635), has a diameter of 1 cm, bulb length of 4.5 cm, and wall thickness (assumed) 0.1 cm. The inside volume is therefore is  $\sim 2.2 \text{ cm}^3$ , and the surface area is  $\sim 14 \text{ cm}^2$ .

Thus in one year, we have

$$p_i = 14 k_i \Delta p_i (3.2 \times 10^7 \text{ s}) / 0.22 = 2.0 \times 10^9 k_i \Delta p_i.$$

In air, the helium and neon have concentrations of 5.2 and 18.2 ppm, or  $4 \times 10^{-3}$  and  $1.4 \times 10^{-2}$  torr, respectively. We then have, after one year, the following partial pressures in a borosilicate glass bulb (still ignoring the time constants):

Component	$p_i(\text{torr, 1 yr})$
Helium	$4.0 \times 10^{-5}$
Neon	$3.4 \times 10^{-8}$

We must consider a lifetime requirement of about 2-3 years. Thus a borosilicate glass tube will reach a pressure of about  $1 \times 10^{-4}$  torr of helium; the neon is negligible. Stanford tests long ago (see J. Crawford notes) indicate substantial degradation of performance at  $\sim 10^{-3}$  torr of helium for a much larger tube. RCA (now Burle) suggested (25 years ago, verbal communication) that  $10^{-4}$  torr would be a fairly safe limit.

Thus for the Hamamatsu R1635, helium leakage might become significant if there were a launch delay of several years. For the R4868, the situation is only slightly better, because the ratio of volume to surface area is only slightly larger. For the R5611, the ratio of volume to surface area is better than for the R1635 by a factor of almost 2. For the R4443 that we are using (13.5 mm diameter, 71 mm length, wall thickness 1.2 mm), the volume to surface area is about 25% better than that of the R1635, and the thicker wall (1.2mm v 1.0) adds additional margin. Thus excess helium concentrations should be avoided, but special efforts to reduce helium levels below the normal atmospheric concentration are not needed.

### Conclusions:

1. The PMT's must not experience extended time intervals with helium levels substantially in excess of that in air (5 ppm). If there is any risk of such elevated helium levels, monitoring is essential.
2. Some provision for reducing the helium level around the PMT's is required. Bagging and purging with standard dry nitrogen planned for the LAT (< 1 ppm helium) is acceptable.